ISRU: Using biology to produce food and oxygen from resources on Mars. B.M. Link[1], C. D. Quincy[2], R.M. Wheeler[3], G.D. Massa[3], A.E. O'Rourke[3], [1]Southeastern Universities Research Assoc., Kennedy Space Center, (Bruce.M.Link@NASA.gov), [2]NASA, UB-I Kennedy Space Center (Charles.D.Quincy@NASA.gov), [3]NASA, UB-A Kennedy Space Center.

Introduction: Any crewed mission to Mars is a "biological" mission. As we move farther away from Earth, we will have to produce the required food, water and nutrient resources to sustain the crew in route or on the surface of other planetary bodies. Critical nutrients, like vitamins, have been shown to degrade in our current food system [1] and represent a risk to long term crew health. One way to address this problem is by developing reliable Biological Life Support Systems (BLSS) that can provide fresh, nutrient-rich foods. [2] Much work in this area will be done as we learn to live and work on the Moon. Systems developed for the Moon should also work on Mars, but will not be designed to take advantage of resources that Mars offers: CO_2, more abundant water, and a day length similar to Earth's. The photosynthetic portion of a BLSS can act as an ISRU element on Mars by providing human life support needs. There is an urgent need to understand how to build components of a fully functional BLSS. One Mars Exploration Program Analysis Group (MEPAG) goal relates to this area.

MEPAG Goal IV, Sub-Objective C1: Understand the resilience of atmospheric *In Situ* Resource Utilization (ISRU) processing systems to variations in Martian near-surface environmental conditions. MOXIE [3] is the first demonstration of ISRU of the Mars atmosphere by conversion of CO_2 to O_2 and CO. This is useful for generating fuel for a return trip to Earth. Biology, however, can utilize CO_2 directly from the Martian atmosphere particularly if there is a clean, available water source. Photosynthesis converts light energy, water, and CO_2 to O_2 and sugar (glucose) that is then converted to foods or plant biomass. Plants not only make food this way but also produce essential vitamins, antioxidants and oils key to crew health and revitalize air at the same time. Producing Vitamins B_1 and C on Mars may be essential to a crew survival because they show substantial degradation over time [1]. A photosynthetic chamber is a key module of any BLSS capable of sustaining crews on long-duration missions.

An early demonstration of this type of module on Mars will provide necessary engineering data for developing longer missions and require few resources and little crew time. Pressures of 10 – 20 kPa are sufficient for plant growth and may negate the need for a ballast gas like nitrogen or argon that are also readily available on Mars [4] [5].

Objectives and Scenarios: The primary science objectives mapped to mission scenarios are: **Objective 1)** Demonstration of oxygen generation and plant growth (robot lander only, or scenario I.) No crew time is required. **Objective 2)** Demonstration of food safety, nutrient production, and replanting (scenario I, II, III). One to four crew hours would be recommended for replacing the "plant seed mat" one time, taking, processing and testing, plant samples. The unit could be landed and activated on a robotic lander prior to crew arrival and visited one or more times by the crew depending on the mission and availability. One design option would allow the module to be brought into a pressurized workspace for servicing. If a seed crop is grown, a gram of seed could be easily returned to earth for study. Return of freeze-dried, or frozen samples would be recommended but not required. **Objective 3)** Production of multiple crops and supplementation of crew diets by providing key nutrients and antioxidants. (Scenario IV, II, III depending on robotics). Return of freeze-dried, or frozen samples would be desirable unless key nutrients can be measured on Mars. If metagenomics analyses are available (scenario II, III, IV), beneficial and pathogenic agents could be identified on Mars.

The mass of a fully functional plant growth module could be limited to 10 kg. If the chamber is well insulated, and can use ambient light, then the power draw could be from 80 - 300 watts. This is an area that requires active research and is highly dependent on if the module is installed inside or outside of a crew module (Wheeler, 2004).

Concept of Operations: For objective 1) the simplest concept of operation for the module is to land it (robotically) on Mars in a dormant state situated near the sunward surface of the lander. At activation, the unit and water supply (40 mL, brought from Earth) would be warmed and held at 22 ºC. The Mars atmosphere would be used to supply 1- 2 KPa of CO_2 and 10 KPa of O_2 (from a bottle) is needed at startup. The vapor pressure of the water vapor would add 2 KPa [6] [7]. Seeds would be automatically watered, and an insulated window cover or light pipe would allow sunlight to enter the chamber during the day but prevent heat escape at night. An internal camera would show growth (one frame per day, one sensor reading per day). Sensors would record, temperature, pressure, RH, CO_2, O_2, and reservoir levels. More atmosphere would be pumped in if the

CO_2 levels drop below setpoint or O_2 climbed too high. Amperage could be monitored on an air flow fan as a proxy for air speed. No crew time is needed to achieve Objective 1.

For objective 2) at the end of a growth cycle, crews would sample and test the plants, using simple kits: colorimetric assays, antibody tests (total down mass < 200 g packaged). Polymerase Chain Reaction (PCR) or metagenomics tests could be performed if available for other experiments providing a full picture of the microbiome including beneficial and pathogenic organisms. A crew would replace the seed mat for the second grow out and refill the reservoir (estimated at 50 mL). If sample return is available, the first mat could be freeze-dried by venting it to the Martian environment through a filter, preventing the escape of earth life, then bagged for a return to Earth (200 g fully packaged). On return, elemental analysis (by inductively coupled plasma (ICP)), Multi-omics and some nutrients could be measured. Total crew time would be from one to four hours.

For objective 3) Some cleaning would be needed between subsequent grow outs. Total crew time would be from four to six hours each time the unit was harvested, cleaned and restarted. Restarts would be four to eight weeks apart depending upon the crop. Tests would remain as for objective 2). If there is a mass spectrometer available for another experiment, the chamber gas could be sampled for compositional analysis. If there were a Minion® sequencing type of device as part of the habitat (scenario IV) or rover (scenario III) metagenomics could be done to characterize the microbiome and biofilms after each subsequent growth test. Human microbiomes, investigated using metagenomics, will be important to the crew so this very small, lightweight sequencer is likely to be a part of any habitat module. Water (40 – 200 mL) would be needed from the potable water supply to replenish reservoir water. If there was the capacity to return frozen plant samples, some would be taken for this purpose. Full return mass could be limited to 500 g fully packaged if there are freezer resources on the return vehicle. If no freezer is available, then sample return is the same as for objective 2 (200 g fully packaged.)

Recommended Special Tools: Most tools required do not need to be specialized to the unit, but screw drivers and a wrench set would be needed. Specialized tools would include cleaning brushes, preplanted plant mats, and a specialized carrier for exposing harvested plant mats to the Martian environment to freeze dry them prior to returning samples to Earth. This carrier would likely mass 500 g and would not be part of the return mass. Other recommended resources to have on later missions (Scenarios II, III and IV) would be a sequencing system (Minion or equivalent), metagenomics reagents, and computational power similar to a PlayStation 4 loaded with a 50 Gb or larger sequencing data base. This would allow for metagenomics work to be done on Mars with no sample return (estimated down mass of 10 kg). The computational resource can service multiple payloads or be used to meet other needs.

It is likely that there will be a mass spectrometer (MS) landed with the mission. If it could be made "multi-purpose" then more science possibilities emerge as more chemistry and analysis could be conducted on Mars without the need for returning the samples to Earth. It would be beneficial to a crewed mission to have liquid and gas chromatography available using the MS as a detector. This allows for identification of multiple chemistries including the search for amino and nucleic acids on Mars (search for Mars or Earth life MEPAG goal I and IV, D.) This mass allocation could be divided between different science packages and is approximately 20 kg down mass.

References

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